

FY94 End of Fiscal year Letter
(01 Oct 1993 - 30 Sep 1994)

ONR CONTRACT INFORMATION

Contract Title: Tunable Antennas Using Thin Film Ferroelectrics

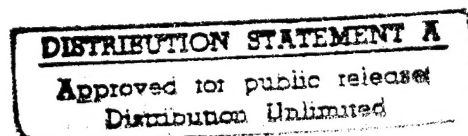
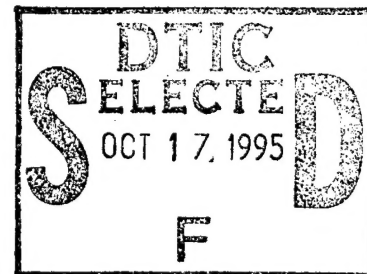
Performing Organization: University of Colorado

Principal Investigator: Dr. John C. Price

Contract Number: N00014-93-1-0592

R & T Project Number: Film013---01

ONR Scientific Officer: Dr. Wallace Smith



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Enclosure (1)

A. Description of the scientific research goals

This contract is a portion of a joint effort between the Department of Physics, University of Colorado; the Cryoelectronic Metrology Group, NIST-Boulder; and the Naval Air Warfare Center, Weapons Division, China Lake. There are military needs for greatly improved airborne detection of sources of electromagnetic radiation in the VHF and UHF bands. Many of the applications could be met using electrically small antenna elements in a superdirective array, provided the losses in the antenna structure can be made small enough and bandwidth limitations are overcome with dynamically tunable matching networks. We are seeking to demonstrate a solution to these problems by combining thin film ferroelectric capacitors (to create electrically tunable matching networks) with high temperature superconductors (to create low loss antenna structures). We will fabricate and test a half-loop antenna designed to meet a specific military application: mid-course guidance for missiles. The results of this program will allow evaluation of this technology for use in a broad range of guidance and avionics applications. In parallel with the antenna fabrication we will develop ferroelectric thin films with highly tunable dielectric constants and low loss tangents, at low temperature (77K) and high frequency (500 MHz and above). The dielectric properties of the ferroelectric films will be studied using a newly developed microstrip resonator technique which allows measurement of both loss tangent and dielectric tunability over a wide frequency range. Information obtained from the dielectric measurements will allow us to optimize the antenna design and predict performance.

B. Significant results in the past year:

A large number of microstrip resonator test structures have been fabricated and tested in the last year, and our microstrip resonator characterization technique has been refined. The dc bias to the ferroelectric capacitor is now applied using retractable probes whose location along the microstrip may be adjusted to coincide with a voltage minimum. In this way we can bias the capacitor without introducing losses or complicating the circuit modeling. Six resonant modes can now be observed from 6 GHz to 22 GHz and the losses due to the ferroelectric can be clearly separated from other losses. Measurements of tuning and loss tangent of SrTiO₃ films at 76 K and 4 K have been published using the refined method. Tunability, dielectric constant, and loss tangent all appear to be frequency independent over our frequency range. However, the loss tangents vary from 0.004 to 0.020, increasing with increasing temperature and decreasing with increasing voltage bias. Antennas are now being fabricated at NIST based on the measured properties of the SrTiO₃ films and on design work that has been done at China Lake. A first antenna without the contact metalization has already been delivered to China Lake and used to make adjustments to the test fixture which will be used for radiation measurements. A working antenna with single-sided YBCO will be delivered at the beginning of January, and we expect to deliver a two-sided device by the end of January.

C. Plans for next year's research:

This is the last year of this program. We are seeking additional funding for closely related work.

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Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

D. List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals

"Frequency Dependence of h/e Conductance Oscillations in Mesoscopic Ag Rings," John B. Pieper and John C. Price, *Physical Review Letters* **72**, 3586 (1994).

"A sensitive low-power homodyne reflectometer for impedance measurements at 0.25–1.0 GHz," John B. Pieper and John C. Price, *Rev. Sci. Instrum.* **65**, 445 (1994).

"Correlation Functions for Mesoscopic Conductance at Finite Frequency," John B. Pieper and John C. Price, *Physical Review B* **49**, 17059 (1994).

"Characterization of a Tunable Thin Film Microwave $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}/\text{SrTiO}_3$ Coplanar Capacitor," David Galt, John C. Price, James A. Beall, and Ronald Ono, *Applied Physics Letters*, **63** (22), 3078–3080 (1993).

"Observation of the Aharonov-Bohm effect at finite frequency in mesoscopic Ag rings," John B. Pieper and John C. Price, *Proceedings of the XXth International Conference on Low Temperature Physics*, Eugene, Oregon, August 4–11, 1993 [*Physica B* **194-196**, 1051–1052 (1994)].

"Transport properties of ultrathin Pd films," Y. Liu and John C. Price, *Proceedings of the XXth International Conference on Low Temperature Physics*, Eugene, Oregon, August 4–11, 1993 [*Physica B* **194-196**, 1351–1352 (1994)].

"Oxide Superconductors and Ferroelectrics—Materials for a New Generation of Tunable Microwave Devices," A.M. Hermann, R.M. Yandrofski, J.F. Scott, A. Naziripour, David Galt, John C. Price, J. Cuchiaro, R.K. Ahrenkiel, *Proceedings of the Molecular and Oxide Superconductors Conference*, Eugene, Oregon, 1993 [*Journal of Superconductivity* **7**, 463 (1994)]. (Text of an invited talk.)

2. Non-Refereed Publications and Published Technical Reports

"Dielectric properties of thin film SrTiO_3 grown on LaAlO_3 with $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ electrodes," Huey-Daw Wu, Frank S. Barnes, David Galt, John C. Price, James A. Beall, *Proceedings of the SPIE-ISOC Conference on High- T_c Superconductors and Applications*, SPIE Proceedings Vol. 2156, January 1994. (Text of an invited talk.)

"Tunable High Temperature Superconductor Microstrip Resonators," James A. Beall, Ronald H. Ono, David Galt, John C. Price, 1993 IEEE MTT-S International Microwave Symposium Digest.

"Tunable Microwave Devices Using Ti-Ba-Ca-Cu-O High-Temperature Superconductors and $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ Ferroelectric Thin Films," R.M. Yandrofski, A.M. Hermann, John C. Price, J.F. Scott, A. Naziripour, David Galt, H.M. Duan, M. Parathaman, R. Tello, J. Cuchiaro, R.K. Ahrenkiel, *Proceedings of the 183th Meeting of the Electrochemical Society*, Honolulu, May 16–21, 1993. (Text of an invited talk.)

"Frequency-Tunable Microwave Resonator Using Tl-Ba-Ca-Cu-O High Temperature Superconductor and Voltage-Biased $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ Ferroelectric Thin Films," A.M. Hermann, A. Naziripour, R.M. Yandrofski, David Galt, John C. Price, Proceedings of EUCAS '93-European Conference on Applied Superconductivity, Göttingen, Germany, Oct. 4-8, 1993. (Text of an invited talk.)

"Tunable Microwave Devices Using Tl-Ba-Ca-Cu-O High-Temperature Superconductors and $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ Ferroelectric Thin Films," A.M. Hermann, John C. Price, J.F. Scott, R.M. Yandrofski, A. Naziripour, David Galt, H.M. Duan, M. Paranthaman, and R. Tello, Proceedings of Materials and Crystallographic Aspects of High T_c Superconductivity (part 3, p.406), A NATO Advanced Study Institute, Erice, Italy, 17-29 May 1993. (Text of an invited talk.)

3. Presentations

- a. Invited (See above those invited talks for which written text has been published. Listed below are only invited talks with no published text.)

"Mesoscopic Conductance Oscillations at 1 GHz," John C. Price, March meeting of the American Physical Society, Pittsburgh, March 21-25, 1994.

"Tunable Antennas Using Thin-Film Ferroelectrics and High Temperature Superconductors," John C. Price and David Rudman, ARPA Ferroelectrics Program Review, Albuquerque, January 27-28, 1994.

"Quantum Motions of Electrons in Metals," John C. Price, Penn State, Physics Department Colloquium, October 13, 1994.

"Quantum Motions of Electrons in Metals," John C. Price, Colorado State University, Physics Department Colloquium, October 24, 1994.

"Quantum Motions of Electrons in Metals," John C. Price, University of Colorado, Physics Department Colloquium, October 26, 1994.

b. Contributed

"Ferroelectric Thin Film Characterization Using Superconducting Microstrip Resonators," David Galt, John C. Price, James A. Beall, Todd E. Harvey, 1994 Applied Superconductivity Conference, text submitted to IEEE Trans. Appl. Superconductivity.

"Oscillations of the Superconductor-Normal Boundary Conductance," David Betz, Maxim Rivkin, and John C. Price, March meeting of the American Physical Society, Pittsburgh, March 21-25, 1994.

"SQUID Microsusceptometry of Isolated Mesoscopic Aluminum Rings," Xiaxian Zhang and John C. Price, March meeting of the American Physical Society, Pittsburgh, March 21-25, 1994.

"Ionization of Charge-Anticharge Pairs in Ultrathin Palladium Films," Y. Liu and John C. Price, March meeting of the American Physical Society, Pittsburgh, March 21-25, 1994.

"Aharonov-Bohm Oscillations in Disordered Mesoscopic Superconductors," Y. Liu, John C. Price, and Xiaxian Zhang, March meeting of the American Physical Society, Pittsburgh, March 21-25, 1994.

"Strontium Titanate as a Superconductor," John C. Price, Low Temperature Bag Lunch, University of Colorado, April 21, 1994.

4. Books (and sections thereof)

None.

Enclosure (2)

E. List of Honors/Awards

<u>Name of Recipient</u>	<u>Institution</u>	<u>Sponsor and Purpose</u>
John C. Price	U. of Colorado	ONR Naval Young Investigator (1990-1993)
John C. Price	U. of Colorado	Packard Fellowship (1990-1995)
John C. Price	U. of Colorado	NSF Presidential Young Investigator (1990-1995)
John C. Price	U. of Colorado	Sloan Fellowship (1991-1993)
Arnold Leitner	U. of Colorado	Volvo Fellowship student travel expenses (1994)

Enclosure (4)

H. SUMMARY OF FY94
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/PARTICIPANTS
(Number Only)

	<u>ONR</u>	<u>non ONR</u>
a. Number of Papers Submitted to Referred Journal but not yet published:	<u>2</u>	<u>1</u>
b. Number of Papers Published in Refereed Journals:	<u>6</u>	<u>1</u>
c. Number of Books or Chapters Submitted but not yet Published:	<u>0</u>	<u>0</u>
d. Number of Books or Chapters Published:	<u>0</u>	<u>0</u>
e. Number of Printed Technical Reports & Non-Referred Papers:	<u>5</u>	<u>0</u>
f. Number of Patents Filed:	<u>0</u>	<u>1</u>
g. Number of Patents Granted:	<u>0</u>	<u>0</u>
h. Number of Invited Presentations at Workshops or Prof. Society Meetings:	<u>7</u>	<u>0</u>
i. Number of Contributed Presentations at Workshops or Prof. Society Meetings:	<u>4</u>	<u>1</u>
j. Honors/Awards/Prizes for Contract/Grant Employees: (selected list attached)	<u>3</u>	<u>0</u>
k. Number of Graduate Students and Post-Docs Supported at least 25% this year on contract grant:	<u>1</u>	<u>3</u>

Grad Students:	TOTAL	<u>1</u>	<u>3</u>
	Female	<u>1</u>	<u>0</u>
	Minority	<u>0</u>	<u>0</u>
Post Doc:	TOTAL	<u>0</u>	<u>1</u>
	Female	<u>0</u>	<u>0</u>
	Minority	<u>0</u>	<u>0</u>

Enclosure (4)

1. Number of Female or Minority PIs or CO-PIs

New Female	<u>0</u>	<u>0</u>
Continuing Female	<u>0</u>	<u>0</u>
New Minority	<u>0</u>	<u>0</u>
Continuing Minority	<u>0</u>	<u>0</u>

Enclosure (4) contd.